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Paul J.J. Welfens

Explaining oil price dynamics

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Paul J.J. Welfens

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EUROPEAN INSTITUTE FOR INTERNATIONAL ECONOMIC RELATIONS
Bergische Universität Wuppertal, Campus Freudenberg, Rainer-Gruenter-Straße 21, D-42119 Wuppertal, Germany
Tel.: (0)202 – 439 13 71
Fax: (0)202 – 439 13 77
E-mail: welfens@uni-wuppertal.de
www.euroeiiw.de

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Summary: The price dynamics of oil and other non-renewables is a complex field of theoretical and empirical analysis. The Analysis takes the Hotelling rule as an analytical point of departure – basically relevant for the supply-side dynamics – and also considers resources demand, which is assumed to negatively depend on the price of oil and positively on net real wealth of the private sector (wealth and real income are, of course, related to each other through the interest rate). The net wealth variable is of particular interest in the approach presented, which emphasizes, that pricing of non-renewable resources should be considered in the context of portfolio analysis and the role of wealth, respectively. The fairly standard assumption, that the change in the price of natural resources per unit of time is a positive function of the excess demand in the oil market, implies a differential equation, which shows how crucial the role of oil inflation expectations are. If those expectations are below a critical level, there will be stable long run oil price. If, however, the expected oil inflation rate exceeds the critical value, there will be an ongoing increase of the oil price. From this perspective, it is clear that the long run price developments of natural (non-renewable) resources are strongly shaped by global expectation dynamics. To the extent that global real demand shocks or restrictive shifts in monetary or credit expansion dynamics occur, oil inflation expectations could switch from the range of above the critical inflation expectations to below such range, which then amounts to a price regime shift. Such a shift obviously has occurred during the transatlantic banking crisis and the following global recession. A somewhat alternative short-term analytical approach considers oil pricing in the context of a broader portfolio model – thus, oil and several standard financial assets are considered. Policy makers should consider both volatility issues and the challenges of sustainable growth.

Zusammenfassung: Die Preisdynamik von Öl und anderen nicht erneuerbaren Ressourcen ist ein komplexes Feld der theoretischen und empirischen Analyse. Die Analyse nimmt die Hotelling-Regel als analytischen Ausgangspunkt - sie ist relevant für die Angebotsdynamik - und betrachtet auch die Ressourcennachfrage, die negativ vom Ölpreis und positiv vom realen Nettovermögen des privaten Sektors abhängig ist. Die Variable des Nettovermögens ist in diesem Ansatz von besonderem Interesse. Der Ansatz betont, dass die Preisbildung nicht erneuerbarer Ressourcen im Kontext der Portfolioanalyse und die Rolle der Vermögenshaltung betrachtet werden sollten. Die Standardannahme, dass die Änderungsrate des Preises von natürlichen Ressourcen eine positive Funktion des Nachfrageüberschusses auf dem Ölmarkt ist, impliziert eine Differenzialgleichung, die zeigt wie kritisch die Rolle von Ölpreisänderungserwartungen ist. Sind diese unterhalb eines kritischen Wertes, gibt es einen langfristig stabilen Ölpreis. Wenn jedoch eine kritische Erwartungsgröße überschritten wird, gibt es einen anhaltenden Ölpreisanstieg. Von daher ist klar, dass die langfristige Preisdynamik in das erhebliche Maß durch Erwartung gesteuert ist. Wenn es negative globale reale Nachfrageschocks gibt oder restriktive Änderungen in der Geld- oder Kreditexpansion auftreten, dann werden gerade die kritischen Ölpreiserwartungen betroffen. Eine derartige Änderung hat offensichtlich im Kontext der transatlantischen Wirtschaftskrise und der folgenden globalen Rezession stattgefunden. Ein analytisch modifizierter Ansatz erklärt die Ölpreisdynamik im Kontext eines breiteren Portfoliomodells - Öl bzw. Standard Finanzaktiva werden als Anlage alternativ betrachtet. Die Wirtschaftspolitik sollte sowohl Volatilitätsfragen als auch die Herausforderungen des nachhaltigen Wachstums berücksichtigen.

Prof. Dr. Paul J.J. Welfens, Jean Monnet Chair for European Economic Integration, European Institute for International Economic Relations (EIIW) at the University of Wuppertal, Rainer-Gruenter-Str. 21, D-42119 Wuppertal, Phone: +49-202-4391371, Fax: +49-202-4391377

welfens@eiiw.uni-wuppertal.de, www.euroeiiw.de

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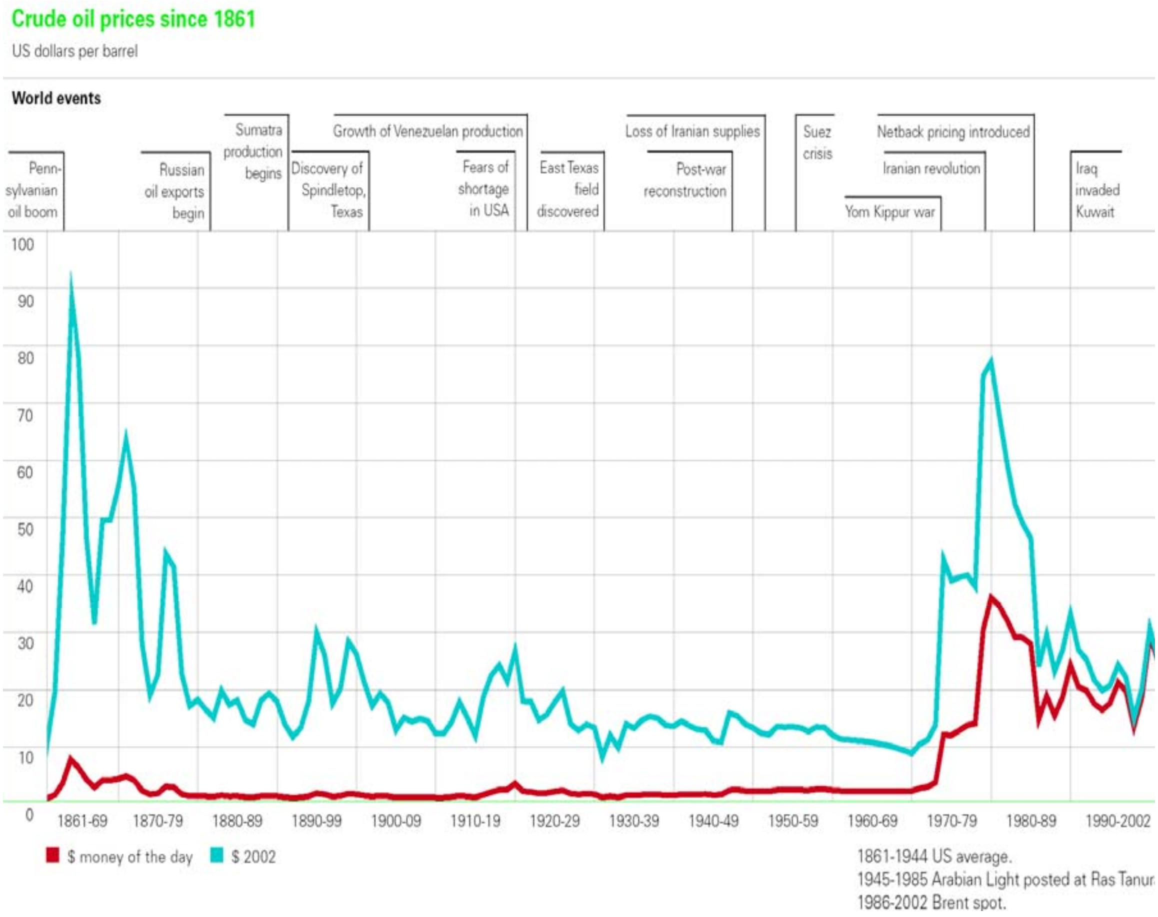
1. Introduction

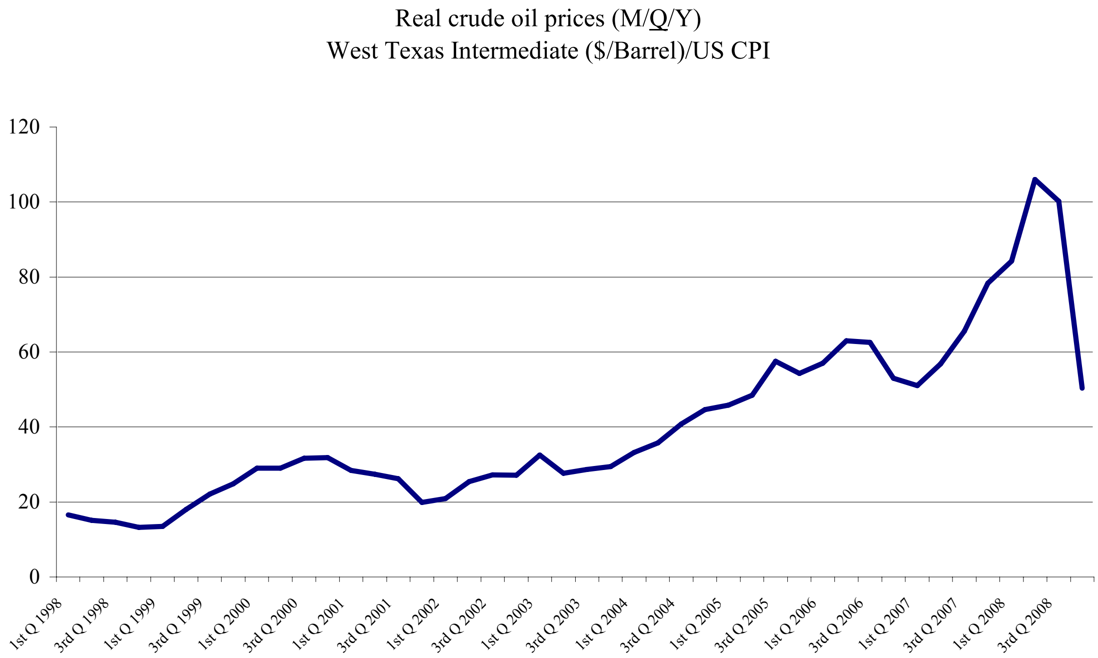
Oil and gas prices have shown an enormous volatility over the past decades, and there are few approaches which explain such long-term price dynamics in a consistent way (e.g. Dées et.al, 2008; Habib et.al., 2009). Standard modelling takes a look at the supply side and the demand side. This is often enriched by the specific focus on cartel pricing in the context of the OPEC. Another standard approach is the Hotelling rule, however, for which one finds only weak empirical evidence in the literature. As regards oil price dynamics the following graphs show nominal and real oil price developments.

Figure 1: Crude oil prices (1861-2002)



Source: BP (2006)

Figure 2: Real crude oil prices (1998-2008)



Data source: OECD, own calculations , Base year 2000=1

With financial market globalization, there is an increasing role for a portfolio-analytical perspective. It is quite useful – as shown subsequently – to explain oil price dynamics in the context of an augmented Branson Model. The standard workhorse for the analysis of short-run dynamics is the Branson (1977) portfolio model – with money (M), domestic bonds (B) and foreign bonds (F*), which jointly explain the exchange rate (e: in price notation) and the nominal interest rate (i). Net wealth of the private sector is A'= M/P + B/P + eF*/P and the desired share of assets are assumed to be proportionate to A' (P is the output price level). In a system of flexible exchange rates, the portfolio model determines e and i on the basis of given stocks M, B and F* (denominated in foreign currency); F* will rise if there is a current account surplus. A simple, long-term approach to exchange rate determination is the purchasing power parity P=ΩeP*, where Ω≠1 for the case of heterogeneous tradable goods (* denotes foreign variables). By including oil as an asset in the representative portfolio (for simplicity one of the standard assets is dropped), we gain considerable new insides into the price dynamics. Besides this approach, it is also useful to consider a market model in which the demand for the natural resource (R) negatively depends on the price of that resource (P") and positively on real wealth of the private sector (A'). As can be shown, the change in the price of oil (dP"/dt) is a function affected by several variables which takes into account the Hotelling rule in an adequate way (it is useful for describing the supply side of the oil market). Quite important is the expected oil price inflation rate π''^{E}. If the expected oil price inflation rate is below a critical value, there will be a stable equilibrium oil price. As can be shown, the case of expected oil price inflation rate exceeding the critical value will lead to sustained oil price inflation. The following analysis presents two theoretical approaches, the final paragraph draws some conclusions.

2. Oil price dynamics in a double perspective

Modified Hotelling rule: Critical role of oil inflation expectations

Let us focus on a simple portfolio model which sheds new light on the well-established debate about the pricing of non-renewable natural resources (on that debate see e.g. Stiglitz, 1974; Dasgupta/Heal, 1979; Sinn, 1981; Roeger, 2005; Welfens, 2008). The basic insight of the traditional debate is an intertemporal decision rule, which says that there will be indifference between producing today – yielding cash flow expressed in \$, namely P" - H" (where H" is the unit price of producing oil in \$ units; P" is the oil price in \$) – and producing tomorrow. We assume that the producer of the natural resource – we will assume that this is oil – wants to invest the cash flow abroad. Producing today will bring (with i* denoting the world nominal interest rate; E stands for expectation, * for foreign variables) at the period's end a unit revenue of i*[P" - H"] if one assumes that the cash flow is invested abroad/in the US; producing tomorrow (we denote the expected oil price as $P"^{E}$) will generate a yield of ($dP^{E}"/dt$) per unit. Take the simple case of perfect foresight and we can derive from the equilibrium equation i*[P"- H"] = dP"/dt the equilibrium expression – after dividing by P": dlnP"/dt = i*[1 - H"/P"]. For the case of H"=0 this expression is the Hotelling rule, namely that the oil price inflation rate will be equal to nominal interest rate.

If the ratio H"/P" were constant over time, the implication simply is that the growth rate of oil prices will be equal to the world interest rate times [1 - H"/P"]. To the extent that monetary policy is expansionary, we should expect a short-term fall in the nominal interest rate, but a long term rise in the interest rate, provided that the expansionary policy course raises the expected inflation rate. Moreover, if (denoting the US inflation rate of non-oil products as π'* and the share of non-oil products on the price index by α'*), we assume that the world real interest rate i* in the long run will be equal to the real growth rate of global output (dlnY*/dt) and we have i* = dlnY/dt + α'*π'* + (1-α'*)π"*. Thus, we can indeed restate the equation as π"α'* [1-H"/P"].= [dlnY*/dt + α'*π'*] [1-H"/P"]. From this equation, the profit-maximizing growth rate of the oil price inflation is obtained as π" =[dlnY*/α'] +π'. Turning back to the fundamental equation, we can write dlnP"/dt = (dlnY*/dt + dlnP*/dt)[1-H"/P"] and assuming that H"/P" is constant (H':=H"/P") the integration of that equation – with C" denoting a constant to be determined from the initial period - yields

(1) lnP"(t) = [1 – H'] [lnY*(t) + lnP*(t)] + C"

From this we have that the elasticity of P" with respect to world output and to the global price level (read US price level), respectively, is [1- H'], which is smaller than unity. Therefore the growth rate of global oil price inflation should be influenced by global output growth and the global inflation rate. Note that our fundamental equation could be modified to include technological progress in the sense that over time a higher share of the oil reservoir in a given resource site can be extracted. If the relevant progress rate – which must not be confused with a reduction of H" in real terms – is denoted as a', we can write i*[P"- H"] = $dP"^{E}$/dt[1+a']; Assuming that H"=ß"R (R is resource extraction) and using the approximation 1/[1+a'] ≈ 1-a', we can state the equation i*(1-a')(1- ß"R/P") = ($dP"^{E}$

/dt)/P”. Let us assume for simplicity that ß”R/P” is close to zero (close to reality for the case of Quwait); we thus can take logarithms and use the approximation that $\ln(1+x) \approx x$ so that we get the crucial equation lni* - a’ –ß”R/P”= lnπ”^{E}, where lnπ”^{E} denotes the logarithm of the expected oil price inflation rate (taking logarithms requires to impose the assumption that the oil price inflation rate is positive). Thus in a supply-side perspective, we have for a given R in the short run the optimum price P” = ß”R/(lni*-a’- lnπ”^{E}). In P”-R space the supply curve is a ray through the origin. Hence the current oil price will be higher, the lower the interest rate i* (read: the US interest rate), the higher the rate of technological progress a’, and the higher π”^{E} are. This is a simple supply-side perspective of the oil market and suggests that expansionary US monetary policy – reducing i* – will raise the oil price. Obviously, the best policy to reduce the oil price in the short run is to try to raise the progress rate on the side of energy users and thus to start policy activities which reduce the expected oil price inflation rate (e.g. an OECD initiative which would encourage substitution of oil through other energy sources or a global program to improve energy efficiency through more intensive research and development could be useful here.)

The above equation can also be rearranged in a way that the medium term optimum supply is determined, namely as a function of P”, the world interest rate, the growth rate of technological progress in terms of “site deepening” and the expected oil inflation rate: Hence R = P”(lni* - a’ - lnπ”^{E})/ß”. We will assume (with the parameter ζ>0) that the change in the oil price is a positive function of the excess demand: dP”/dt = ζ(R^d -R^s). If one assumes that the current demand R^d for oil is a negative function of the oil price P” and a positive function of wealth [A’:= M/P + eF*/P + P’K/P], we can write R^d = - Ω”P”+ Ω”’A’+ R_0 (Ω” and Ω”’ are positive parameters, R_0 is autonomous demand for oil, e’ is the Euler number, t the time index; C’ a constant to be determined from the initial conditions); and we get:

(2) dP”/dt = ζ[-Ω”P”+ Ω”’(M/P + eF*/P + P’K/P) +R_0 - P”(lni* - a’ - lnπ”^{E})/ß”]

Here it is assumed that R_0, wealth and the term (lni* - a’ - lnπ”^{E})/ß” are exogenous

(2’) P”(t) = C’e’exp{- ζ [Ω”+ (lni* - a’ - lnπ”^{E})/ß”]t} +

+{R_0 + Ω”’(M/P + eF*/P + P’K/P)}/[Ω”+(lni* - a’ - lnπ”^{E})/ß”].

This solution of the differential equation converges towards a stable steady state solution {…}/[…] if ζ[Ω”+(lni* - a’ - lnπ”^{E})/ß”]>0; in this case we have a Non-Hotelling rule with the special case of a long term price increase of zero. Moreover, the implication is that a critically high expected oil price inflation rate implies that that there is no steady state solution, namely if lnπ”^{E}> ß”Ω”+ lni* - a’: the price P”(t) will rise at a constant rate; thus we have established a modified Hotelling rule for this specific set of parameters. As i* is equal to the real interest rate r* plus the expected inflation rate which in turn (with π’ denoting the inflation rate of non-oil-products) is α’π’^{E} + (1-α’)π”^{E} the critical condition can now be written – assuming for simplicity that α’ + [(r + α’π’^{E})/π”^{E}] is close to zero – as [(r + α’π’^{E})/π”^{E}]< -ß”Ω”+a’+α’: The critical condition thus reads π”^{E}>(r+α’π’^{E})/(a’+α’-ß”Ω”) and hence a fall of the real interest rate or a’ exceeding a critical value or ß” or Ω” falling to a critical value could trigger a shift to an unstable regime in the sense that the economy moves from a setting with a stationary price P”# towards a regime with a sustained oil price inflation. The model presented suggests that P” will be stable over time for a specific set of parameters, however, if there is a critical change of parameters –

including the expected oil inflation rate (which could be manipulated by various players in the global oil markets and certainly could be affected by major international political shocks) – there could be a phase of sustained oil price inflation. Oil price inflation expectations thus play a very critical role for current oil price dynamics.

The steady state solution – if there is one – depends on autonomous demand for oil, real money balances, the real price of stocks P'/P and the real stock of capital K as well as on the net real claims on the rest of the world (eF'/P). The higher e/P – we assume P* as given – the higher the equilibrium oil price level will be. Thus we have a positive long term relationship between P" and e.

Table 1: Success Ratios of Price Forecasts Based on Futures Spreads (Indicator shows the percentage of future spot price changes correctly indicated by forward price movements)

	Crude Oil[2]	Aluminum[2]	Copper[2]	Wheat[3]
12-month futures[4]				
1990:M1–2008:M11	0.84			
	[0.00]			
1998:M1–2008:M11	0.81	0.88	0.93	0.65
	[0.00]	[0.00]	[0.00]	[0.00]
24-month futures[4]				
1998:M1–2008:M11	0.87	0.88	0.89	0.68
	[0.00]	[0.00]	[0.00]	[0.00]

[1]Fraction of periods for which the futures-spot spread correctly
predicted the direction of actual price changes over the following 12 or 24 months.
Values in square brackets denote the statistical significance of the success ratios (see text for details).
[2]New York Mercantile Exchange.
[3]Chicago Board of Trade.
[4]Last observation of the month.

Sources: IMF, (World Economic Outlook 2009, p. 49)

As regards the quality of forecasting medium medium-term oil prices, the IMF (2009: see table above) shows that future prices on average correctly indicate with an 80% probability the development of future spot prices. If, however, the "failed forecasts" concern relatively large oil price changes the implication points to serious problems: From an investor perspective, it is quite important to anticipate correctly the relatively large swings of oil prices. Misallocation of investment in the resources sector also should be avoided from an economic policy perspective.

Portfolio-theoretical approach to oil markets

An alternative model with which to understand the oil price developments involves a portfolio-theoretical approach, and it is interesting to consider to which extent the implications are in line with the modified Hotelling rule established here. Let us consider such a portfolio approach in a US perspective so that all assets are denominated in $. We thus consider foreign bonds, money and oil as the three relevant assets. We assume that the share f' of foreign bonds is a negative function of i and the expected oil price inflation rate π"; and a positive function of i*':= i* + a" (a" is the expected depreciation rate). The desired share of oil (u') in the portfolio is a positive function of π", a negative function of i and a negative function of i'* (here the budget constraint is n'+f'+u'=1). The budget constraint reads A'= M/P + eF*/P + P"V"/P so that in the modified portfolio model which contains the money market equilibrium line (MM curve), the equilibrium line for foreign bonds (FF* curve) and the equilibrium line for the oil market (VV curve), only two of the three equations are independent. Thus one can determine in the short-run market – ignoring the production function – the exchange rate e and the resource price P".

(3) A'= M/P + eF*/P + P"V/P

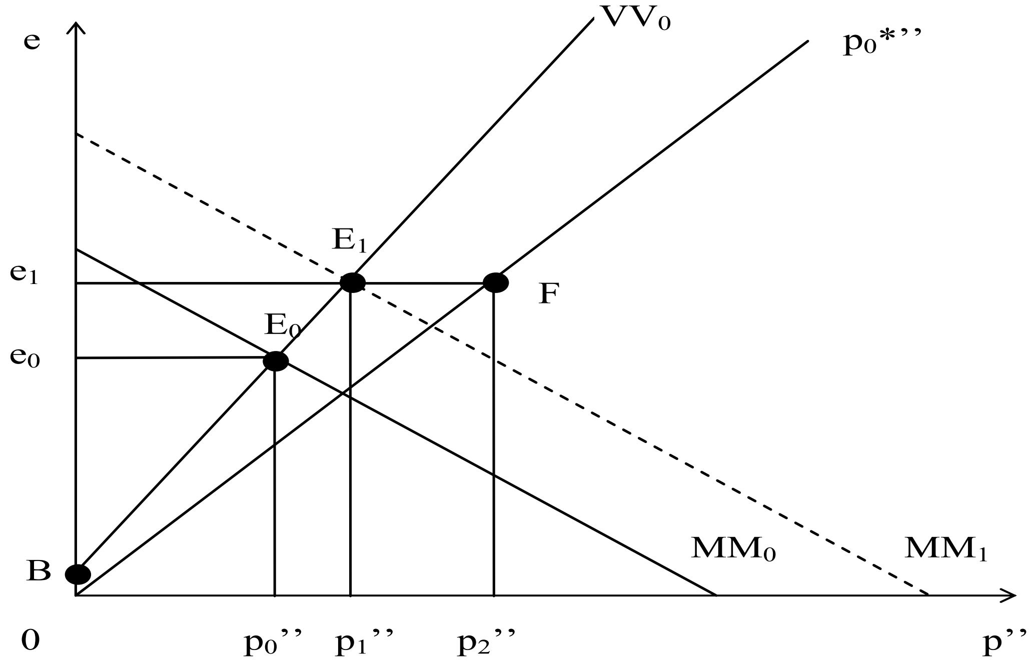
(3') M/P = n'(i, i'*, π")A'

(4) eF*/P = f'(i, i'*, π")A'

(5) P"V"/P = u'(i, i'*, π")A'

In an e-P" diagram, the MM curve has a negative slope while the VV curve – showing the equilibrium in the oil market – has a positive slope. An expansionary monetary policy (through an expansionary open market policy: dM is raised as the central bank buys foreign assets) will bring about depreciation and a rise in the oil price P". If we assume that the oil producer in country II has a target price (in domestic currency) of P_0*", there is a problem to the extent that dlnP"/dM< dlne/dM: The price in foreign currency is P*"= P"/e; as P"= eP"* a target price line P_0*" implies that E_1 cannot be a stable new equilibrium point. Rather, as the oil producer from country II is assumed to have market power, it would rather fix the oil price in $ at the price P_2" instead of P_1". Disregarding this strategic aspect of market power, one may argue that our portfolio-theoretical approach to oil price determination is in line with the logic of the modified quasi-Hotelling rule established above.

Figure 3: Exchange rate and oil price determination in the hybrid-portfolio-model



3. Conclusions

This approach provides new insights into long-term economic dynamics of open economies and innovation. These findings give a theoretical basis for some of the empirical literature, with a focus on the links between stock market pricing and innovation dynamics. As regards medium-term oil price dynamics the international banking crisis and the world recession will bring about a fall of the nominal and the real oil price. Lower oil prices imply reduced incentives for companies to launch energy-saving innovations. It is an open question whether or not the oil price will return 250 $/Barrel before 2015. Growth of world population alone is not a convincing argument to accept a long-term rise of the real oil price – the history of 20th century has indeed shown a relatively stable real oil price (except for the oil price shock 1970s: BP, 2008).

Basic arguments for considering oil markets in a portfolio balance approach were also discussed; linking such an approach with the production function would, however, be fruitful in a broad sense if one should consider a production function with labor, capital, knowledge and oil (or another non-renewable resource). Thus, we have presented some new thoughts on key problems of macroeconomic analysis. If an increasing global energy demand should bring the world economy beyond the peak of oil production (possibly after 2020) one may still hope that an intelligent interplay of market price dynamics and induced innovation dynamics will contribute to global economic prosperity.

Certainly, there are considerable time lags between relative price shifts and induced innovations (Grupp, 1999). The OECD countries and G-20 would be wise to limit financial market volatility and indeed to avoid another major banking crisis.

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